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The Use of Pavement Deflections in Asphalt Pavement Overlay Design

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16. ABSTRACT

Data are provided that show the deflection reducing capabilities of aggregate bases, cement treated bases and asphalt concrete of varying thickness used in the construction of five highway projects in California. A deflection testing procedure is outlined and curves are presented showing additional pavement required to strengthen existing asphalt surfaced pavements.

Deflection of highway pavements as a factor in pavement design and performance has been a subject for consideration by highway engineers in this and several European countries for at least 40 years.

Much of the early work was theoretical in nature and directed toward arriving at a design scheme for Portland cement concrete or rigid type pavements. H.M. Westergaard 1 made the first comprehensive theoretical analysis of stresses and deflections caused by loads acting on rigid pavements in the early 1920's. This work was followed with studies by the Bureau of Public Roads and other organizations in the 1930's and 1940's.

A theoretical approach to using pavement deflections in the structural design of asphalt pavements has been less easily accomplished. However, in recent years, there has been a great deal of work of an empirical nature exploring the relationship between deflections and the design or performance of asphalt pavements. The development of the Benkelman 2 Beam as a rapid means for the measurement of deflections of a transient nature has given special impetus to these studies being conducted by many organizations.

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DEFLECTIONS IN ASPHALT
PAVEMENT OVERLAY DESIGN

E. Zube, R. Bridges 1962

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THE USE OF PAVEMENT DEFLECTIONS IN ASPHALT PAVEMENT OVERLAY DESIGN

ERNEST ZUBE* AND ROBERT BRIDGES**

SYNOPSIS

Data are provided that show the deflection reducing capabilities of aggregate bases, cement treated bases and asphalt concrete of varying thicknesses used in the construction of five highway projects in California. A deflection testing procedure is outlined and curves are presented showing additional pavement required to strengthen existing asphalt surfaced pavements.

INTRODUCTION

Deflection of highway pavements as a factor in pavement design and performance has been a subject for consideration by highway engineers in this and several European countries for at least 40 years.

Much of the early work was theoretical in nature and directed toward arriving at a design scheme for portland cement concrete or rigid type pavements. H. M. Westergaard[1] made the first comprehensive theoretical analysis of stresses and deflections caused by loads acting on rigid pavements in the early 1920's. This work was followed with studies by the Bureau of Public Roads and other organizations in the 1930's and 1940's.

A theoretical approach to using pavement deflections in the structural design of asphalt pavements has been less easily accomplished. However, in recent years, there has been a great deal of work of an empirical nature exploring the relationship between deflections and the design or performance of asphalt pavements. The development of the Benkelman[2] Beam as a rapid means for the measurement of deflections of a transient nature has given special impetus to these studies being conducted by many organizations.

The presently available literature presents information of value on the magnitude of deflections and some indications as to their effect on the design or performance of asphalt pavements. There is still a need for more information which will aid the highway engineer when he is confronted with requests for overload permits, load restrictions during a critical period of thaw or high roadway moisture contents and especially when a decision must be rendered on whether to continue maintaining a section of existing roadway or to reconstruct it.

The literature provides some information concerning critical deflection limits for various thicknesses of asphalt concrete or other asphalt type surfaces. F. N. Hveem presented limiting values for various structural thicknesses in a report, "Pavement Deflections and Fatigue Failures"[3]. Other authorities have proposed higher limiting values. The differences are understandable and it should be expected that each State or each region might justifiably establish limiting values that vary somewhat in magnitude. Available asphalts, aggregate mixes used, asphalt contents used, traffic loading and frequency, weather, maintenance costs and perhaps other factors in combination could lead engineers to reach various decisions to best suit their area of responsibility. For example, one city in Southern California has residential subdivision streets which deflect as much as 0.080 inches under a 7500 pound wheel load. The absence of serious cracking may be attributed to an asphalt rich macadam surface on the streets and a relatively small number of wheel loads in excess of 4000 pounds. With conditions such as these rather high limiting deflection values can realistically be assumed.

Little is available in the literature on the damping effect of different layer thicknesses of various materials. Some organizations have presented information on the necessary asphalt blanket thickness to preclude cracking[4] and others the necessary additional pavement thickness[5]. The AASHO Road Test report will provide some data on this subject.

No data has been published, as yet, on test procedures that will

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permit the prediction of asphalt pavement deflections that will occur for various combinations of soils, aggregates and structural section thicknesses prior to construction of the pavement. Work in the California Division of Highways is nearing this goal using results from the newly developed Resiliometer test and pressure distribution relationships. The first report on this work is being presented at this Conference[6]. The procedure discussed in that report utilizes resiliometer data, which have been correlated with actual pavement deflections, to predict the pavement deflection expected for various structural sections and soils and aggregates to be used in construction. The proposed analysis permits the selection of the proper structural section which will meet all design criteria and result in pavement deflections near limiting values for the selected structural section.

DAMPING EFFECT OF DIFFERENT LAYERS OF MATERIALS.

Recent experiences of the California Division of Highways concerning the damping effect of different layer thicknesses of various materials, testing methods used, a proposed design approach for reconstruction necessary to preclude cracking in an existing asphalt surface and some examples of application are discussed in this report.

California has measured deflections during many investigations of pavement behavior since 1938. The primary purpose of this work was and is the gaining of a more thorough understanding of how the magnitude of transient deflections may be related to pavement behavior.

During the past 4 years a program has been followed in gathering deflection measurements for various asphalt surfaced roads which are incurring increasing maintenance costs. Because of these maintenance costs, plans have been and are being made to blanket or completely reconstruct the pavements to provide a more satisfactory facility. In general, the roadways were originally constructed by the State or by the counties in the 1920's and 1930's. As part of the State Highway System, many of the roadways have been widened, shoulders constructed and the traveled way blanketed with one or more layers of asphalt surfacing or they will soon require such improvements. The characteristic condition of many of these projects, so studied, is the predominance of "alligator" or "chicken-wire" cracking or in the case of cement treated base, "block" cracking in the surfacing.

Some of the projects need reinforcement of the traveled way now but funds cannot be made available for major reconstruction unless justified by engineering data. Frequently the reconstruction consists of removal of obvious and isolated areas of serious distress by "digout" and replacement of base along with a new asphalt blanket for the full width of roadway. The selection of blanket thickness of 1, 2 or 3 inches has been based solely on the personal experience of the engineers assigned the task. The pavements on some projects, reconstructed with what was thought to be a sufficient thickness of AC blanket, have cracked badly within 1-3 years and have required another blanket. These occurrences have lead to disagreements between experienced engineers on how much remedial work needs to be done and what thickness of asphalt concrete blanket is necessary and acceptable.

During the past four years California has endeavored to utilize deflection measurements as a guide to the overall suitability of an existing pavement, to pick out "soft spots" that should be improved by digouts and replacement of base materials and as another part of the evidence on which a decision to blanket or rebuild the roadway should be based. More than 25 individual projects have been extensively studied up to the present time.

DEFLECTION MEASURING EQUIPMENT USED BY CALIFORNIA.

Several types of equipment have been used by California in making deflection measurements. First was the General Electric Travel Gauge used from 1938-54[3], later the Benkelman Beam - 1954 to present[2] and since 1960 a device designated as the "Traveling Deflectometer[7]" which has been developed by the Materials and Research Department. The first two devices need no description since they are well known and have been adequately covered in the literature. Figure 1 is a photograph of the Traveling Deflectometer equipment.

This large device utilizes one

or more beam type probes which can be placed at transverse positions such that deflections resulting from load carrying dual tired wheels may be determined at a maximum of 4 points across a roadway lane at any one time. The equipment is so arranged that while traveling at 1/2 to 3/4 mph down the roadway, deflections can be measured at any selected point in a longitudinal direction at intervals greater than 12-1/2 feet in both the inner or outer wheel tracks or at any other transverse point in the lane of travel other than directly under the tires. The deflections are electronically recorded as a continuous trace.

DEFLECTION MEASURING PROCEDURE.

Prior to actual deflection testing a reconnaissance is made of the roadway to prepare a general condition survey and select representative test sections within which deflection tests are to be made. The information collected for the general condition survey is as follows:

1. Project identification such as job number, highway district, county, route and section. Geographical, mileage or engineering station limits are also recorded.

2. Construction details including project length, width and number of lanes along with contract numbers by which the work was constructed and structural section information such as type and thickness of subbase, base and surfacing.

3. Maintenance history.

4. Amount and type of cracking and patching.

5. Average rut depth.

A typical condition survey form is attached as Figure 2.

California has not, as yet, used a numerical condition rating index because of the extensive variations in pavement construction and conditions which can be found on a State Highway System. This subject is being studied, however, and at present it appears that functions of pavement deflection, roughness as measured by the California profilograph, rut depth and amount of cracking and patching can be incorporated into a rating index. It will remain to be seen whether any such index will produce any results better than a rating by an experienced engineer or maintenance superintendent.

Once the condition survey is completed test sections are selected which include representative portions of the roadway which can be easily tested with available deflection testing equipment. The sections are not selected at uniform intervals because of traffic control problems on vertical and horizontal curves and because it is desired to test those stretches of pavement which include the greatest visible cracking distress. The reasons for this, of course, are that many times a roadway must be blanketed when only a portion of the surface is seriously distressed. The distress quite often covers less than 50 percent of the roadway area yet substantial maintenance or reconstruction is essential to insure a safe, hazard free pavement for today's fast moving traffic. Frequently, it is also desirable to blanket a project just as soon as distress begins to appear to forestall a rapid, serious deterioration of the existing facility. There have been roadways where as little as 5 percent of the pavement has been seriously distressed yet it was considered essential that a blanket be placed.

California practices in selecting test sections are generally as follows:

On two lane roads, less than three miles in length and using the Benkelman Beam, deflections are made at intervals of 50 feet in the lane judged to be representative of the most seriously distressed. Sometimes one half the project is tested in one lane and the second half in the opposite lane. Approximately 300 deflection measurements can be made in one day with one beam, three men and necessary flagmen. Using one beam, the deflection tests are alternated with twice as many being made in the right or outer wheel track as compared to the left or inner wheel track. On four lane projects, less than three miles in length, the testing is generally done in the travel lanes in much the same manner as above.

During the deflection testing phase a note is made at each test point regarding whether the pavement is cracked or not within 2 to 5 feet of the test point. During the data analysis phase these notes help to establish the reasons for differences in deflections between cracked and uncracked areas.

On projects longer than three

miles in length, when the Benkelman Beam is used, test sections 1000 feet long are selected in each mile of pavement and an analysis similar to the above is made. The data are evaluated on the basis of each mile of pavement.

When the traveling deflectometer is used the usual practice is to test continuously at 13-15 feet intervals in both wheel tracks. Approximately 3 lane miles of pavement can be covered easily in one day. On longer projects a scheme of random scanning is used. This method consists of moving along the highway testing at 6 to 25 or more points at intervals of 13-15 feet in either wheel track, skipping an area and then testing in another short stretch. The intervals between and lengths of pavement tested are quite variable and random. The Deflectometer operator selects the areas to be tested based upon his observations of the pavement condition. This scheme permits testing at intervals on 10-20 miles of roadway in a day's time and the collection of 1200 to 2400 deflection measurements. A crew of 3 men and necessary flagmen is required for this operation.

Costs, including field testing and data analysis are in the order of $60 per mile of pavement tested for both the Benkelman Beam and Traveling Deflectometer operations. It must be noted, however, that the Deflectometer will produce much more data for the same cost.

Once the deflection test measurements are obtained they are tabulated, analyzed and the mean deflection determined for the inner and outer wheel path of each test unit. The mean deflection appears to be the most satisfactory measure that can be conveniently applied at this time although more involved statistical approaches have been considered and used.

Following are the results of deflection testing on several projects in California. Five of these projects provide relationships between deflection and increasing thicknesses of layers of gravel, asphalt surfacing or cement treated bases. The other two projects are concerned with the application of the deflection data to the selection of overlay thickness.

PROJECT I - I-HUM-1-G

The northwest coast of California is adjacent to a mountainous, forested region which has presented some difficult highway construction problems because of high rainfall, marshy areas, springs, poor drainage, and, during the spring and winter months, poor drying conditions, land slides and generally unstable formations. Recently, a project under construction in this area had reached the construction phase of being nearly graded, with some elements of the structural section being placed while wet cuts and subdrains were being excavated at other locations. Numerous wet, "spongy" areas had developed in the basement soil subgrade. The start of the rainy season was only a few weeks away.

Because a cement treated base was included in the design of the structural section, it was considered undesirable to place and try to compact such a rigid layer over a yielding subgrade. Consequently, a quick method of locating all soft spots and remedying the problem was needed.

The Benkelman Beam truck with a 15,000 pound axle load was used on the project to pick out the location and extent of the excessively soft areas present along the grade. Remedial action including digouts, addition of gravel blankets and aeration of existing inplace materials were initiated as the result of the deflections observed. Gravel being plentiful in the vicinity permitted the use of thicknesses up to 42 inches to reduce excessive deflections originally in the order of 0.070 to 0.100 inches.

Figure 3 presents data obtained from this study. Since the basement soil deflections averaged 0.070 inches and generally ranged from 0.080 to in excess of 0.100 inches in the softer areas it appears that 24 inches of gravel damped out about 50% of the basement soil deflection. The resulting deflection level of 0.040 to 0.050 inches provided a satisfactory foundation for the placement of an 8 inch thick cement treated base. The problem of isolated soft spots and possible rupture of the CTB were eliminated or markedly reduced.

Final deflection measurements

on the completed cement treated base averaged 0.010 inches, a reduction of approximately 0.030 inches or about 0.003 to 0.005 inches per inch of cement treated base. The better deflection reducing ability of the cement treated base as compared to gravel is mainly considered to be the result of the stiffness of the layer effecting changes in pressure distribution in the underlying materials.

The effect shown on Figure 3 for similar thicknesses of gravel being able to reduce deflections of prepared subgrades on other projects in other areas is conditioned by at least three factors. One of these is the inherent internal resilience of the gravel layer being used to damp deflections on the prepared subgrade. Even though the resilience of aggregates is generally low, an aggregate base is subject to relatively high pressures and the resulting deflection can be high. It is easily understood that as the gravel layer increases in thickness the deflections originally determined on the subgrade or basement soil are proportionately reduced. However, deflection from resilience within the gravel layer itself increases with thickness of layer. The net combination of the resilience from all layers will determine whether the overall deflection is reduced and to what degree. The other two factors that affect deflection and resilience are moisture content and density of the soils and aggregates. Still other factors might be presence of organic material, mica, interparticle friction and interlock and cementing or binding action of the soil fraction. The Humboldt County project provides only one arrangement of the possible combinations. Additional data, showing the deflection damping effect of gravel will be presented in the discussion for project IV.

Perhaps, the most difficult problem experienced in this deflection survey operation was the tendency of granular materials to shift under the wheels of the test truck. Since this was almost always an upthrust, some deflection readings were seriously affected and frequently showed values the reverse of those which were expected. The difficulty caused by this upward movement was overcome by driving 8" spikes into the compacted layer for a depth of 7-7½ inches. This provided a firm anchor to resist the shallow upthrust and deflections were made on the heads of the spikes. No difficulty was experienced with upthrust problems after this method was adopted.

Work on this project proved that the Benkelman Beam is an effective device for locating soft spots in prepared grades and provides data that can be utilized in determining the type of remedial action that is necessary.

PROJECT II - V-MON-2-D

The structural design of this project, located on U. S. Route 101 in Monterey County California, about 130 miles south of San Francisco, included 11 inches of aggregate subbase, 6 inches of aggregate base and 7 inches of asphalt concrete (AC) placed in lifts of 3 inches AC base, 2 inches AC level course, 1-1/2 inches of AC surface course and 1/2 inches of AC open graded mix.

The relatively thick, layered AC pavement provided an opportunity to check the damping effect of increasing thicknesses of the AC mixture.

Initial deflections were made, within selected roadway limits, on the surface of the compacted aggregate base (AB). Subsequent deflections were made, within the same limits, on each layer of AC as it was placed and compacted. Deflections were also made on the completed roadway 7-1/2 months after being opened to traffic. Figure 4 is a plot of a selected unit representative of the entire test section and shows typical relationships.

The reduction in initial deflection values measured on the aggregate base as individual AC layers are added is clearly shown. The addition of the 3 inch AC base course had a pronounced effect in some areas such as the vicinity of station 474 (Southbound Travel Lane) and less effect in other areas. Deflection values became more uniform with less dispersion of values after the placement of the 3 inch AC base course. Each successive layer progressively resulted in lower deflections.

The AC mix was still relatively "fresh" on August 10, 1960 when deflection tests were made. The roadway had not been subjected to traffic at that time. After addition of a 1/2 inch open graded AC and the compactive efforts of 7 months traffic the deflection values were lowered appreciably as can be seen by the

March 29, 1961 data. It is not known whether the reduction in deflections from August, 1960 to March, 1961 was the result of added compaction, hardening of the asphalt, changed subgrade moisture conditions, temperature or other effects. Each of these factors probably contributed to some unknown degree with the added compaction by traffic the most likely factor.

Figure 5 is a graph showing the damping effect of successive thicknesses of AC pavement. It appears that one inch of AC surfacing reduces the deflection 7-10 percent or in the order of 0.002 inches to 0.003 inches. Since the initial average deflection for the aggregate base was 0.033 inches it remains to be seen whether these relationships can apply when base deflections range higher or lower. Pavement temperatures during the above measurements were in excess of 70°F in all cases.

PROJECT III - VII-LA-2-C

This project, located on U. S. Route 101 north of Los Angeles was constructed to its present 4 lane divided highway standards during the years 1947 to 1951. The structural section initially consisted of 3 inches of asphalt concrete on 8 inches of aggregate base placed over 13 inches of aggregate subbase. Distress, consisting essentially of alligator type cracking, became pronounced along the route as early as 1953 particularly in the traveled lanes.

The Materials and Research Department began a comprehensive investigation of the causes of cracking in 1954. The report for this investigation included among the findings that the cracking present in the AC surfacing was the result of relatively high deflections, heavy traffic and a prematurely hardened asphalt binder.

Recommendations for reconstructing this project included pulverizing, mixing with cement, placing and recompacting the existing AC surfacing and aggregate base to form an 8 inch cement treated base in the traveled lanes only. Over this was placed a 4 inch AC surface. During construction the decision was made to set aside 2000 lineal feet in one lane for construction of 4 special test sections. These test sections were as follows:

1. 400 lineal feet of new AC surfacing increasing from 3 to 7 inches placed on the existing aggregate base.
2. 600 lineal feet of AC surfacing varying from 2 to 5 inches placed over the existing cracked AC pavement and base.
3. 500 lineal feet same as 2 with asphalt latex added to the asphalt.
4. 500 lineal feet same as 2 with continuous wire mesh embedded in the mix.

The following comments are concerned with the relationship of deflection versus thickness of the AC surfacing for units 1 and 2.

Figure 6 presents data accumulated soon after construction in 1957. Between stations 368 to 374, where an 8 inch cement treated base was used, the average deflection was 0.015 inch under a 15,000 pound axle load. The deflection before reconstruction averaged 0.035 inches. This reduction, resulting from the use of an 8 inch CTB layer and approximating 0.002 to 0.003 inches per inch, was less than that noted for similar construction on other projects.

The deflection measurements between stations 374 and 384 fluctuate in a manner typical of those found for other projects. There is a definite trend to smaller deflections as the thickness of AC increases. The data for this project suggest that, for deflections originally in the area of 0.030-0.040 inches, one inch of additional AC surfacing reduces the deflection by 0.002 to 0.003 inches. This agrees with the data presented from project II.

The final deflections measured between stations 374 to 384 are above critical limits suggested by F. N. Hveem[3] and it would be expected that cracking would develop. Cracking surveys each year since the completion of the work have shown that cracking developed within two years after completion in the fall of 1957 in the vicinity of station 374 and has progressed during the past 4-1/2 years throughout the test section. Cracking is still rather fine, closely spaced and of the alligator type. There is little wheel rutting and it is expected that the pavement will serve well for some years to come although application of a seal coat may soon be desirable. Although the average deflection of 0.015 inch for the cement treated base unit is greater than the suggested critical limit of 0.012 inch, little to no cracking has become manifest during the 4-1/2 years since the pavement was reconstructed.

PROJECT IV - III-SAC-232-A

This project is located between Sacramento and Marysville and was developed initially by the several counties as an agricultural service road. After being incorporated into the State Highway System some years ago the State began developing the route as the most direct highway between Sacramento and Marysville. Two units of the route were reconstructed in Sacramento County during 1959 and 1960. The structural designs for each unit included variations in selections of materials and provided an excellent opportunity to study the comparative deflection damping capabilities of gravel, cement treated base and asphalt concrete.

Unit 1 was constructed with a structural section consisting of 3 inches of AC and 8 inches of cement treated base placed over the existing roadway consisting of an armor coat on a 12 inch gravel base.

Deflection tests were made on two separate occasions on the existing roadway, after placement and compaction of the 8 inch gravel layer to be cement treated, on the gravel layer after cement treatment and one day cure, on the finished AC surface immediately after construction and again seven months after completion. Figure 7 presents deflection data from these measurements. The two distinctly different ranges of deflections on the existing roadway are typical of seasonal variations. The May, 1959 deflections were made near the end of seasonal rains and the September, 1959 deflections after three months of hot dry weather typical of the Sacramento Valley. The average September deflection between stations 278 and 283 was 0.067 inch. After placing and compacting 8 inches of gravel the average deflection dropped to 0.036 inches. Part of this rather large reduction in deflection is believed due to additional compaction of the upper portion of the existing road. After cement treatment of the 8 inches of gravel and one day cure the deflection dropped to an average 0.023 inch. After placing the 3 inch AC surfacing in October, 1959 the deflection averaged 0.013 inches, remaining unchanged 7 months later during April, 1960 when moisture conditions were more conducive to higher deflection measurements. Tests in the spring of 1961 averaged 0.012 inches after a reasonably dry winter season.

The second unit along this route to be studied utilized two structural sections; one section consisted of 6-1/2 inches of asphalt concrete surfacing over 6 inches of aggregate base and the second consisted of 3-1/2 inches of asphalt concrete over 12 inches of aggregate base. Both sections were placed directly on the existing roadway. Figures 8 and 9 provide typical deflection results for these units. Once again deflection tests were made on the old road surface on more than one occasion.

Figure 8 shows that deflection measurements in section II(a) averaged 0.060 inches in July, 1960. After placement of 6 inches of aggregate base the average deflection was 0.052 inches. Addition of 2 inches of asphalt concrete lowered the average deflection to 0.035 inches. A second layer of 2 inches of asphalt concrete lowered the average deflection to 0.031 inches. After a third 2 inch layer brought the total thickness to 6 inches of asphalt concrete the average deflection was 0.032 inches. This slight increase and the obvious disuniformity of results between successive 2 inch layers is believed to be the result of variations in compaction for each layer. Eighteen days later the deflections on the 6 inch layer averaged 0.022 inches. Seven months later in March, 1961, the average deflection had increased to 0.024 inches and still later in October, 1961 the average deflection was 0.012 inches. The increase in the March deflections was presumably the result of spring moisture conditions.

Deflection measurements for Section II(b) Figure 9 for the existing roadway averaged 0.060 inches on July 19, 1960. Placement of 6 inches of compacted gravel lowered the average deflection to 0.036 inches. A second 6 inch compacted layer of gravel lowered the deflection to 0.030 inches. Placement of 3-1/2 inches of asphalt concrete brought the final average deflection on September 20, 1960 to 0.021 inches.

Analysis of the deflection data for the different units of this project is hampered by large variations in results. In general, though, it can be reasonably determined that additional compaction of an existing roadway or material layer will result in lowered deflection, that 8 inches of cement treated base can reduce deflections originating in lower layers by 0.024 to 0.030 inches (0.003 to 0.004 inches per inch) and that asphalt concrete reduces deflections in the order of 0.002 to 0.004 inches per inch when properly compacted and dependent to a considerable degree on the initial deflection level. For example, when placed on a gravel base with a deflection averaging 0.040 to 0.050 inches 6 inches of asphalt concrete can effect a reduction of deflection in the order of 0.020 to 0.030 inches. When placed over a cement treated base the deflection reducing capabilities of asphalt concrete are considerably reduced.

PROJECT V - IV-NAP-8-A

This project, located south and west of Napa, California, was reconstructed in 1954 and 1955 utilizing three different structural sections. Along a portion of an existing PCC pavement the traveled way was widened with 3 inches of asphalt concrete over 8 inches of aggregate base and 6 inches of aggregate subbase. This constituted one of the structural sections. The second section consisted of a 2 inch asphalt concrete contact blanket on the PCC pavement. The third section was on new alignment and consisted of 3 inches asphalt concrete over 8 inches aggregate base and 10 inches of aggregate subbase.

Within one year extensive distress in the form of alligator cracking developed in sections 1 and 3 described above.

During the investigation of this distress a deflection survey was completed which showed that in the cracked areas the deflection averaged 0.033 inches and ranged from 0.006 to 0.063 inches while in those areas where the PCC pavement was blanketed (and where no cracks developed) the average deflection was 0.009 inches and ranged from 0.003 to 0.013 inches.

As a result of the distress investigation corrective repair was suggested as follows: In some areas where "spot" cracking occurred the distressed area was dug out 13-1/2 inches deep and 12 inches cement treated base material was compacted in the cavity and covered with 1-1/2 inches of asphalt concrete. Where the distress was extensive a structural section consisting of 8 inches of cement treated base covered with 3 inches of asphalt concrete was placed directly on the existing pavement.

A deflection survey was made after all repair work was completed with the following results:

Where 8 inches of cement treated base and 3 inches of asphalt concrete was used the average deflection was reduced from 0.034 to 0.009 inches. Where 12 inches of cement treated base and 1-1/2 inches of asphalt concrete was used the average deflection was reduced from 0.036 to 0.011 inches.

THICKNESS OF OVERLAY REQUIRED TO STRENGTHEN EXISTING PAVEMENT

Maintenance engineers and superintendents have long recognized the reasons and been subjected to the forces that make necessary the overlaying and strengthening of existing highway facilities. The forces, simply stated, are public demands. The reasons are public comfort and safety at speeds in keeping with those provided by the highway network in the general vicinity. Modern Freeways and Toll Roads with high traffic densities tend to reduce the public tolerance of pavement imperfections which is considerably different from reaction based on curving mountainous or farm to market roads. The more sophisticated a highway system becomes the greater are the public demands that maintenance be perfect and seemingly minor imperfections become less tolerable.

The attention of a highway maintenance engineer must be focused on the following conditions.

1. Roughness of pavement. This factor is associated with uncomfortable riding qualities and perhaps hazardous driving conditions.

2. Excessive maintenance expenditures. This factor is associated

with weak or worn out pavements. Maintenance superintendents are well aware of the areas of the road system within their responsibility which require disproportionate maintenance.

3. Skid hazard.

4. Anticipated increased traffic loadings. County road departments are frequently faced with this situation in areas of industrial and commercial growth.

5. Public relations. A badly patched road is an eyesore to the community and the road department. Overlays, though rarely justified for this reason, can pay large dividends in public pleasure at having an unsightly condition improved with a thin blanket of pleasing appearance.

Most frequently all of the above reasons are interrelated and associated with the decision to overlay an existing pavement. When roughness, skid hazard or a "beauty treatment" are reasons for overlaying a road, strengthening may or may not be important and the overlay selected will be the minimum that will level up the road or that can be placed by equipment. When an overlay is to be selected to reduce maintenance expenditures or strengthen a weak road to handle increased future traffic some estimate of the present strength and condition of the roadway is needed as well as a knowledge of the increased strength to be gained from successive layers of different materials of various thicknesses.

Deflection measurements are being used to evaluate a pavement's present structural condition. The deflection measurements will also aid in arriving at the answer to the needed strengthening.

California is presently using the curves shown in Figure 10 which give the inches of gravel (which can be converted to equivalent inches of other materials) which must be added to the existing road to lower the present average deflection to within the following critical limits for various materials at a traffic index of 9.0.

Deflection measurements are made under a 7500 pound wheel load (15,000 pound axle load) which is assumed to be the mean value for truck axle loadings on highways having some millions of repetitions. Much of the above discussed work was performed on highways presently rated with very nearly a 9.0 traffic index and this is considered to be a traffic index value that approximates 4-5 million repetitions of a 15,000 pound axle load. Any highway with a larger traffic index must necessarily receive more strengthening and naturally highways with less traffic will require less. This procedure gives weight to the fact that many roads are never subjected to the strain of a 15,000 pound axle load and consequently will never be deflected accordingly.

Listed on Figure 10 are gravel equivalents for various materials used in the construction of highway subbases, bases and surfacings. These were developed from test track data and actual experience and have been in use in California since 1958[8]. These equivalencies are now in the process of revision based on additional experience resulting from deflection studies and analysis of AASHO Road Test results by California.

Once the necessary additional thickness of gravel has been determined from Figure 10 using the average deflection measured and the estimated traffic index, combinations of asphalt concrete and cement treated or untreated base may be selected which will most economically provide the necessary strengthening.

Thickness of Pavement	Type of Pavement	Max. Permissible Deflection
6 in.	Cement Treated Base (Surfaced with Bituminous Pavement)	0.012 in.
6 in.	Asphalt Concrete	0.012 in.
4 in.	" "	0.017 in.
3 in.	" "	0.020 in.
2 in.	" "	0.025 in.
1 in.	Road Mixed Asphalt Surfacing	0.036 in.
1/2 in.	Surface Treatment	0.050 in.

Several projects have been strengthened using this approach. Following are some typical examples for a section of two lane road.

Project VI V-SBt-22-B
North of Hollister, California

Station Limits	Eastbound Lane *OWT	*IWT	Westbound Lane OWT	IWT
120-130	0.068	0.055	0.055	0.062
130-140	0.061	0.046	0.052	0.056
140-150	0.058	0.045	0.043	0.047
150-160	0.054	0.037	0.044	0.036

*OWT Outer Wheel Track
*IWT Inner Wheel Track

Based upon these data it was decided that a representative deflection of 0.060 inches would be assumed for the 4000 feet long section. Using the chart (Figure 10) for a traffic index of 7.8 a thickness of equivalent gravel of 10.4 inches is obtained. If it were contemplated that 3-1/2 inches of asphalt concrete surfacing would be used (gravel equivalent from chart - 4.6) it would require that 5.8 inches of gravel be used as an additional base course. This design would require substantial shoulder improvement. It could be expected that a final deflection in the order of 0.030 inches would result if this structural section were used and if allowance were given to possible compaction of the existing roadway. Reasonable performance for a 3-1/2 inch AC pavement, a 0.030 inch deflection and the fairly low 7.8 traffic index could be expected for 10 or more years.

Another possibility would be reclaiming the existing pavement by the cement treatment of inplace base and asphalt surfacing which would be pulverized and thoroughly mixed. Assuming that 3 inches of badly cracked asphalt surfacing and 5 inches of existing aggregate base are to be intermixed and cement treated to form an 8 inch cement treated base the first task is to determine the existing gravel equivalent involved. It would be 3 (1.00) because of the cracked condition) plus 5 (1.0) or 8.0 inches. To this must be added the additional strengthening of 10.4 inches of gravel already determined from Figure 10 making a total of 18.4 inches. The proposed 8 inches of cement treated base will provide 8(1.72) or 13.7 inches and the remainder (18.4-13.7) or 4.7 inches can be made up with 3.6 inches of asphalt surfacing. In this manner the needed 10.4 inches of gravel strengthening has been accomplished. The final deflection would be in the order of 0.015 inches.

A second example of strengthening a pavement based upon deflection measurements was as follows:

Project VII V-SB-149-D
Between Buellton and Solvang, California.

Average Deflections - Inches

Station Limits	Eastbound Lane OWT	IWT	Westbound Lane OWT	IWT
23-36	0.045	0.046	-	-
23-43	-	-	0.038	0.042
80-90	-	-	0.064	0.064
100-110	-	-	0.069	0.076

The traffic index for this project was calculated to be 6.8. Using the mean outer wheel track (OWT) deflections the following additional structural sections were selected from Figure 10.

Station 23 to 43 5.0 gravel equivalent. Use 3-3/4 in. asphalt concrete.

Station 80 to 110 10.0 gravel equivalent. Use 3-3/4 in. asphalt concrete and 6 in. aggregate base.

This work was completed in early 1961 and deflection measurements were made on the new construction immediately after its completion. The mean outer wheel track deflection in both areas above was 0.025 inches. This is a larger deflection than could be endured for similar AC surface thickness if the traffic index was 9.0 or above. Since the traffic index is only 6.8 it indicates that the deflection equivalent to a 15,000 test axle load or greater will not normally be repeated enough times to effect cracking under actual traffic loadings and consequently it is believed that the pavement will perform well as strengthened. However, it cannot be said to have an extravagant factor of safety.

Recommended reconstruction for projects having substantial areas of cracked pavements need not be as extensive as above. Frequently the situation has been on 4 lane projects that the travel (right) lane is badly broken up and high deflections are measured while the passing lane has few if any blemishes. In this case the full thickness of overlay can be placed on the travel lane and feathered out to nothing across the passing lane if roadway drainage conditions permit.

On one project near San Luis Obispo, California on U. S. Route 101 conditions of cracking and range of deflections were such that the project was subdivided into 6 units. The average deflection for 5 units varied from 0.010 to 0.021 inches and the recommended improvement consisted of placing a seal coat to prevent moisture intrusion through the cracks in the surface. On the sixth unit the average deflection of 0.035 inches warranted a 3-1/2 inch asphalt concrete blanket for an assumed 8.0 traffic index.

The above examples illustrate in a general way, the methods used by the Materials and Research Department for studying the reductions in deflection of the various layers used in the structural section. Also, deflection data from existing highways are used to calculate the required thickness of overlays.

During the next few years we hope to gather additional data to better correlate deflections and their effects on the behavior of asphalt concrete pavements and improve on the selection of additional pavement required to strengthen existing asphalt surface pavements.

ACKNOWLEDGMENTS

The work described herein was performed under the general direction of F. N. Hveem, Materials and Research Engineer. The data gathered represents the efforts of many employees of the Materials and Research Department and it is not possible to acknowledge all of those whose efforts were helpful. However, the writers want to give special credit to Clyde G. Gates, George B. Sherman, Daniel R. Howe and Masayuki Hatano for their splendid work and aid provided in gathering the data used in this report.

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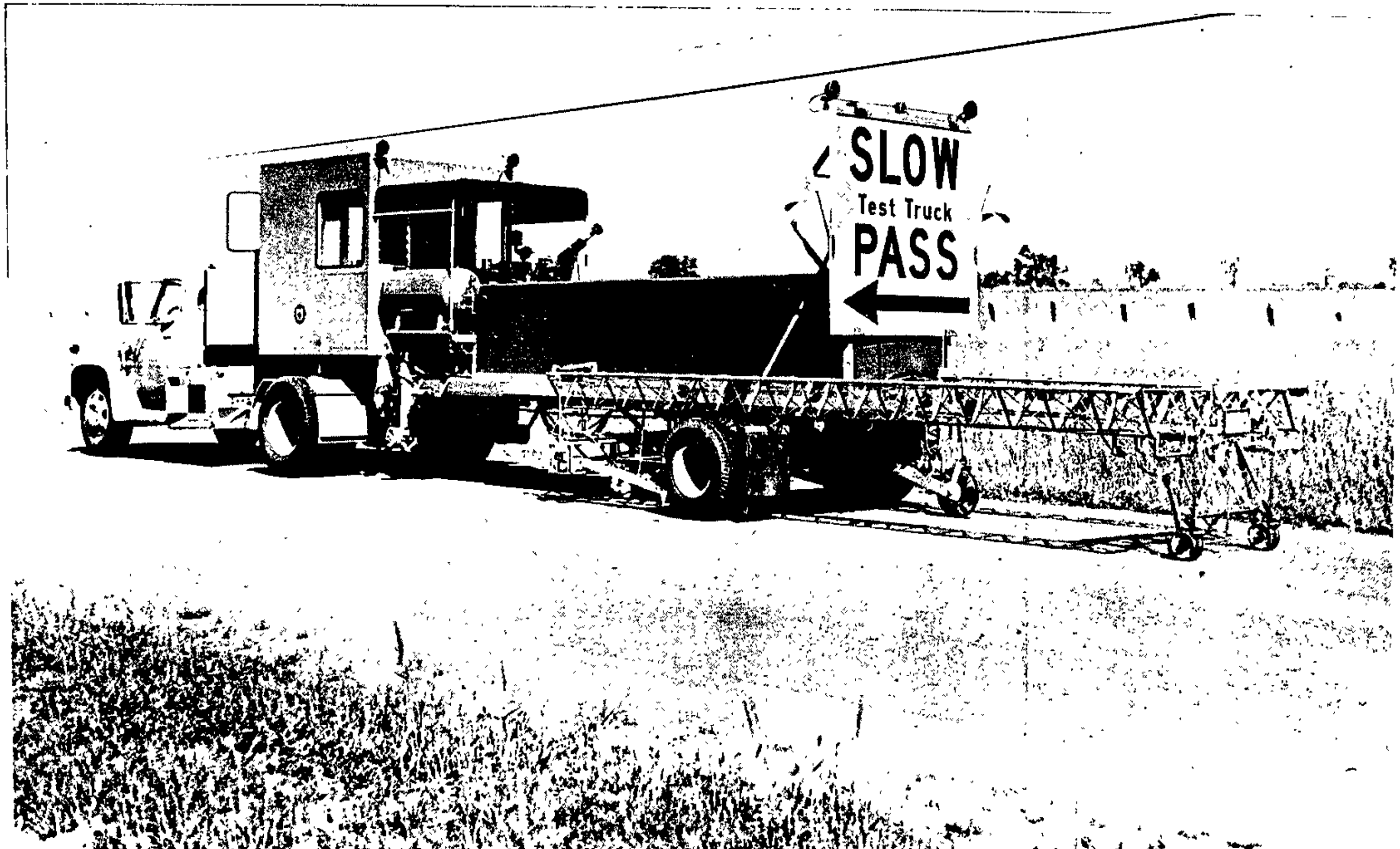

Figure I
TRAVELING DEFLECTOMETER

PAVEMENT CONDITION SURVEY

DIST. _____ CO. _____ RTE. _____ SECT. _____

LIMITS OF PROJECT _____

_____

LIMITS OF SECTION SURVEYED _____

PROJECT NO. _____

TEST SECT. NO. _____

DATE _____

SURVEY NO. _____

CONSTRUCTION HISTORY _____

_____

_____

_____

_____

NO. LANES _____ WIDTH OF LANES _____

TYPICAL SECTION

MAINTENANCE HISTORY _____

_____

_____

VISUAL RATING OF PRESENT CONDITION

0 1 2 3 4 5 6 7 8 9 10

POOR FAIR GOOD VERY GOOD

LANE NO.

UNIT NO.	1	2	3	4	5
Station Limits					
Area of Unit - Sq. Ft.					
Cracking - Sq. Ft.					
Patching - Sq. Ft.					
Average Rut Depth - In.					

REMARKS: _____

_____

Figure 2

DAMPING EFFECT OF ADDITIONAL THICKNESS OF GRAVEL ON BASEMENT SOIL DEFLECTION

I-HUM-I-G

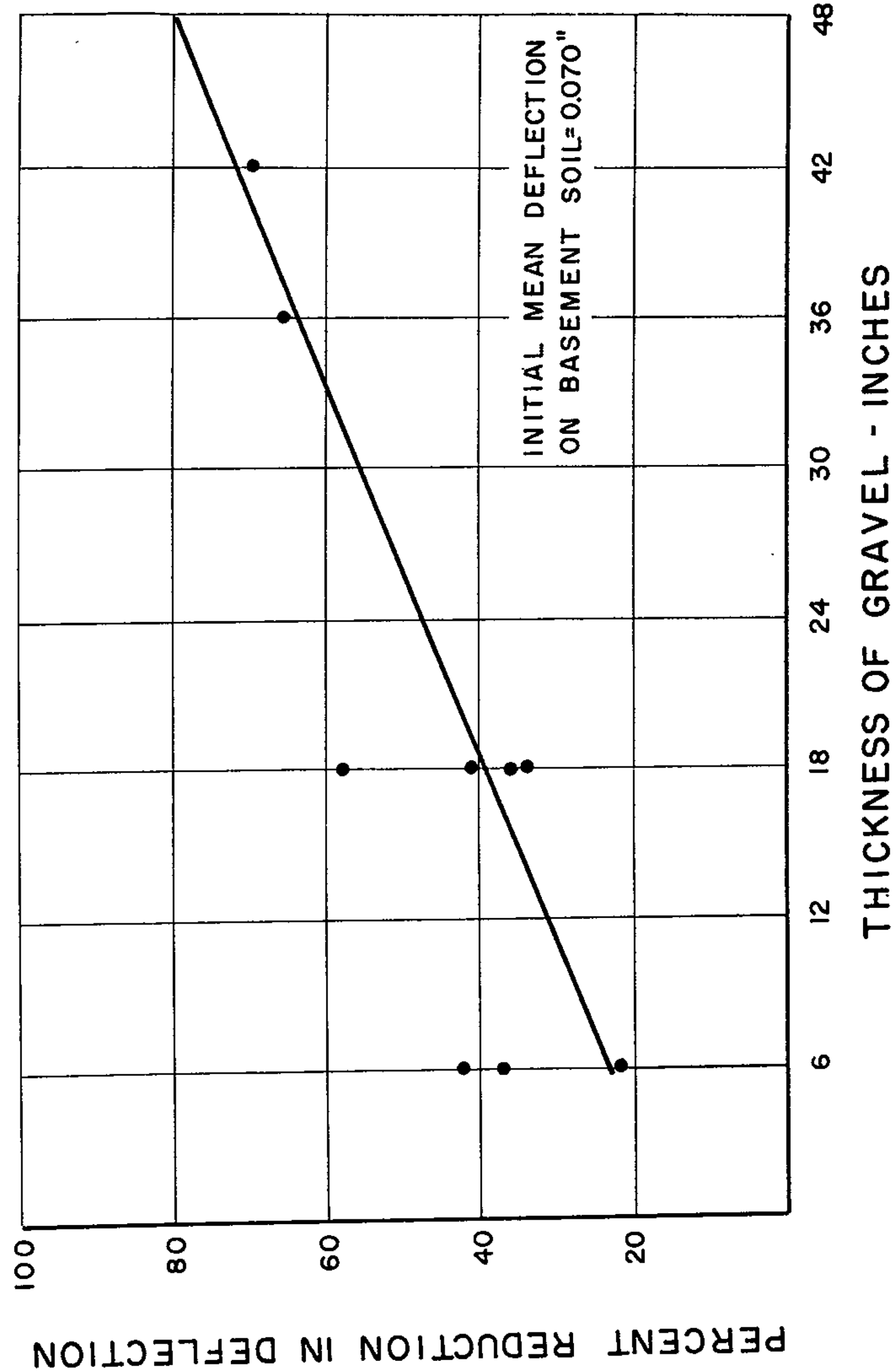

Figure 3

DEFLECTION STUDY
V-MON-2-D

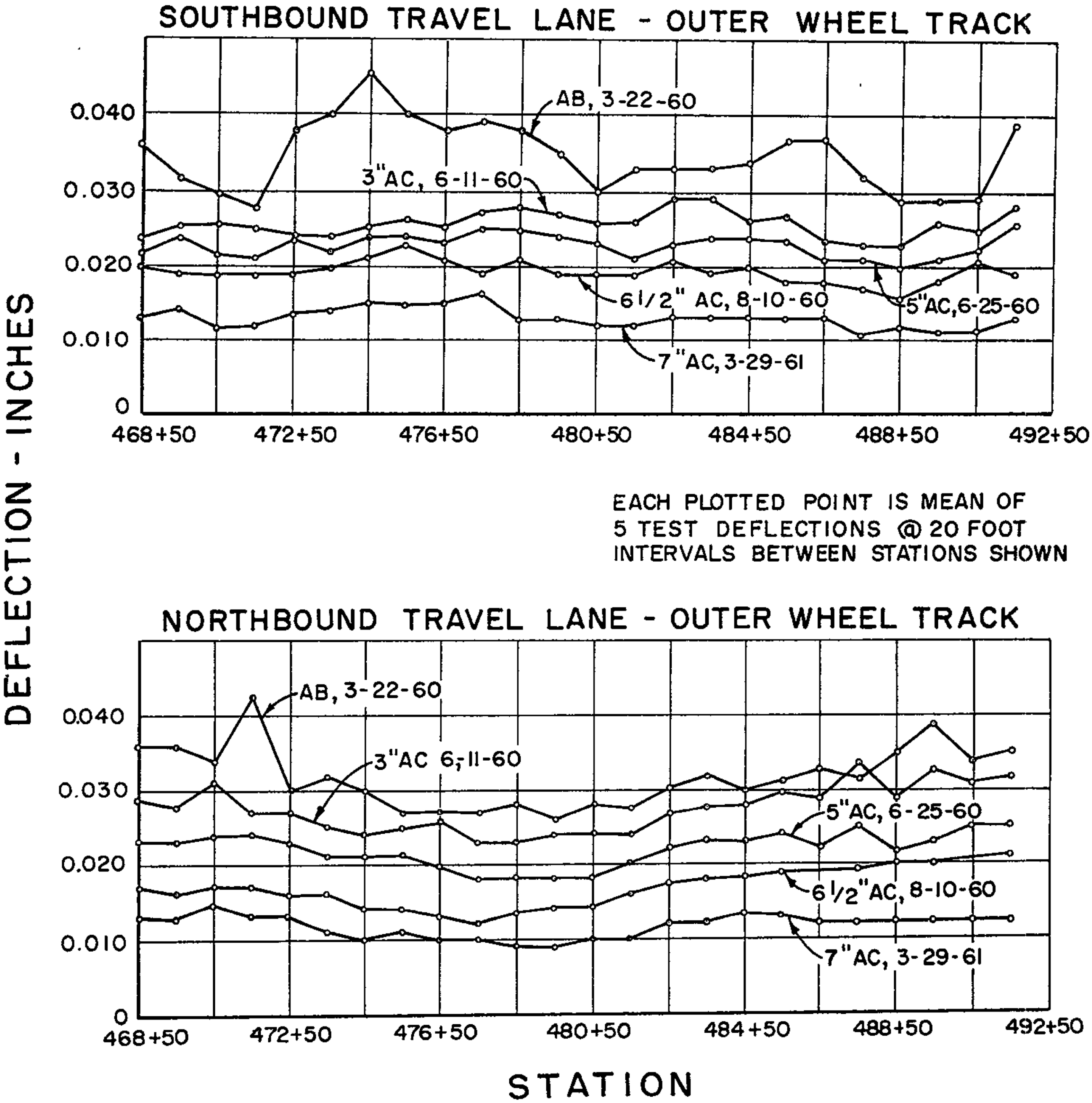

Figure 4

DAMPING EFFECT OF ADDITIONAL THICKNESS OF ASPHALT CONCRETE ON BASE DEFLECTION
V-MON-2-D

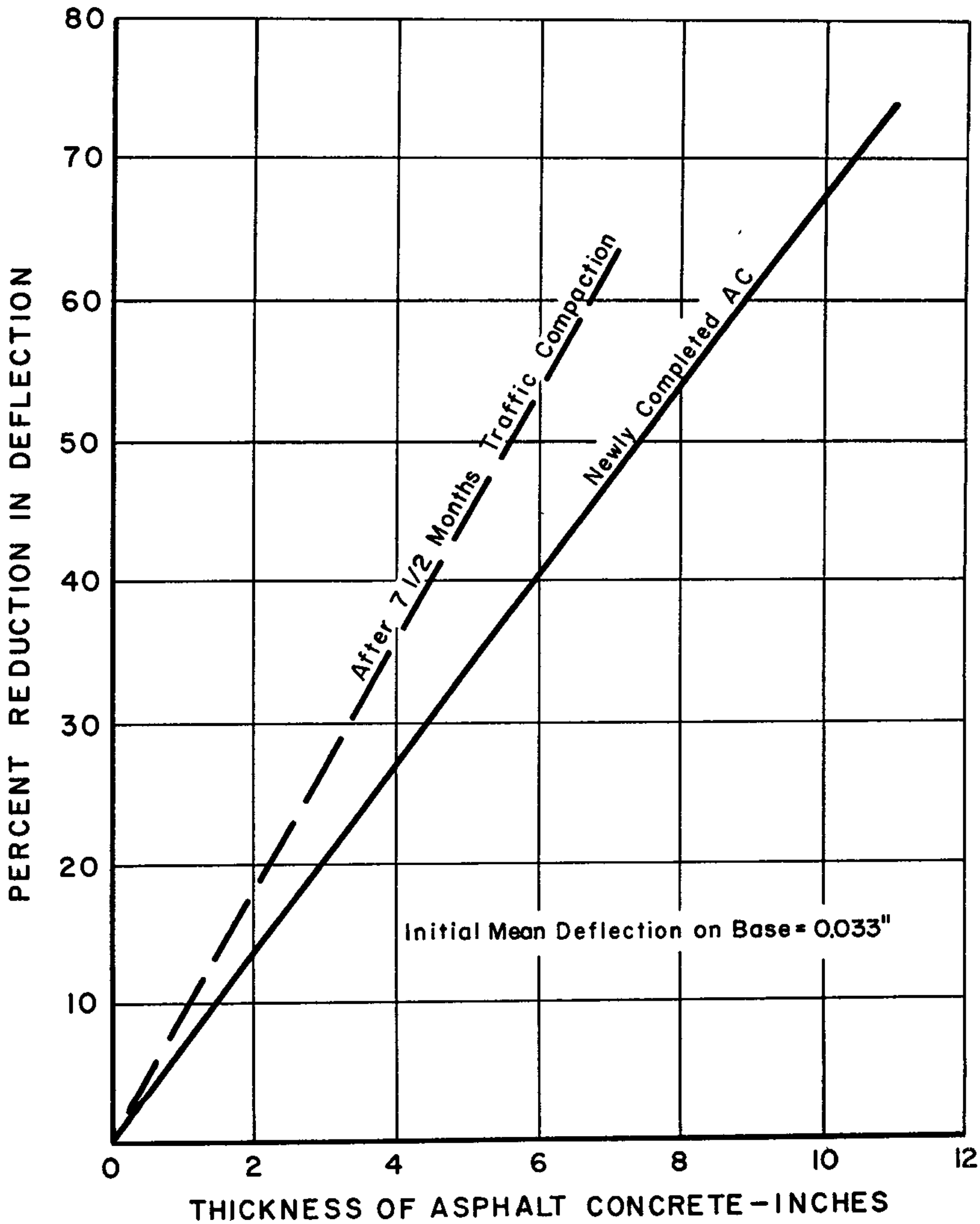

Figure 5

DEFLECTION DAMPING EFFECT OF INCREASING AC SURFACE THICKNESS

VII - LA - 2 - C

TESTS MADE - OCTOBER, 1957

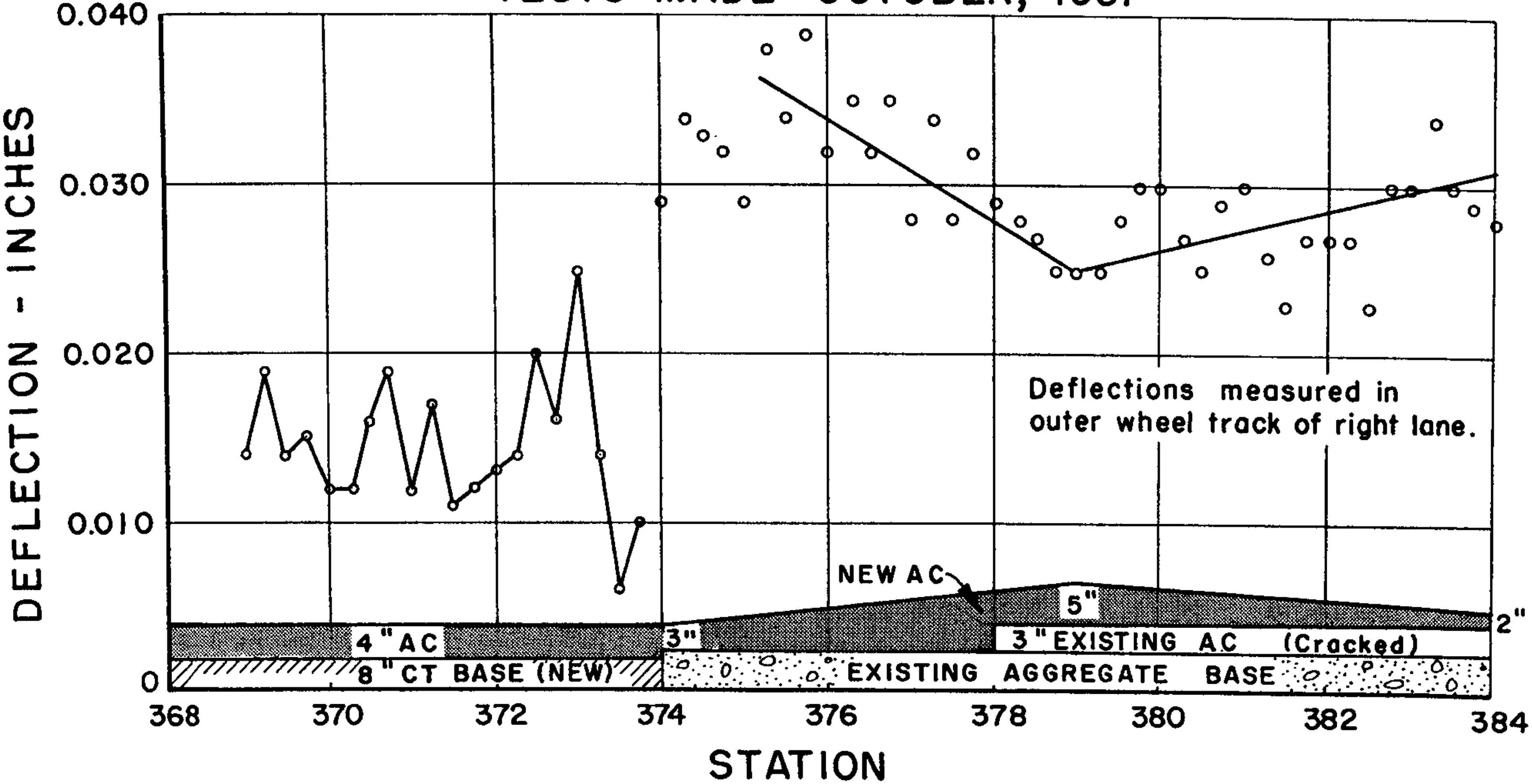

Figure 6

DEFLECTIONS - ROAD III-SAC-232-A
NORTHBOUND LANE - OUTER WHEEL TRACK

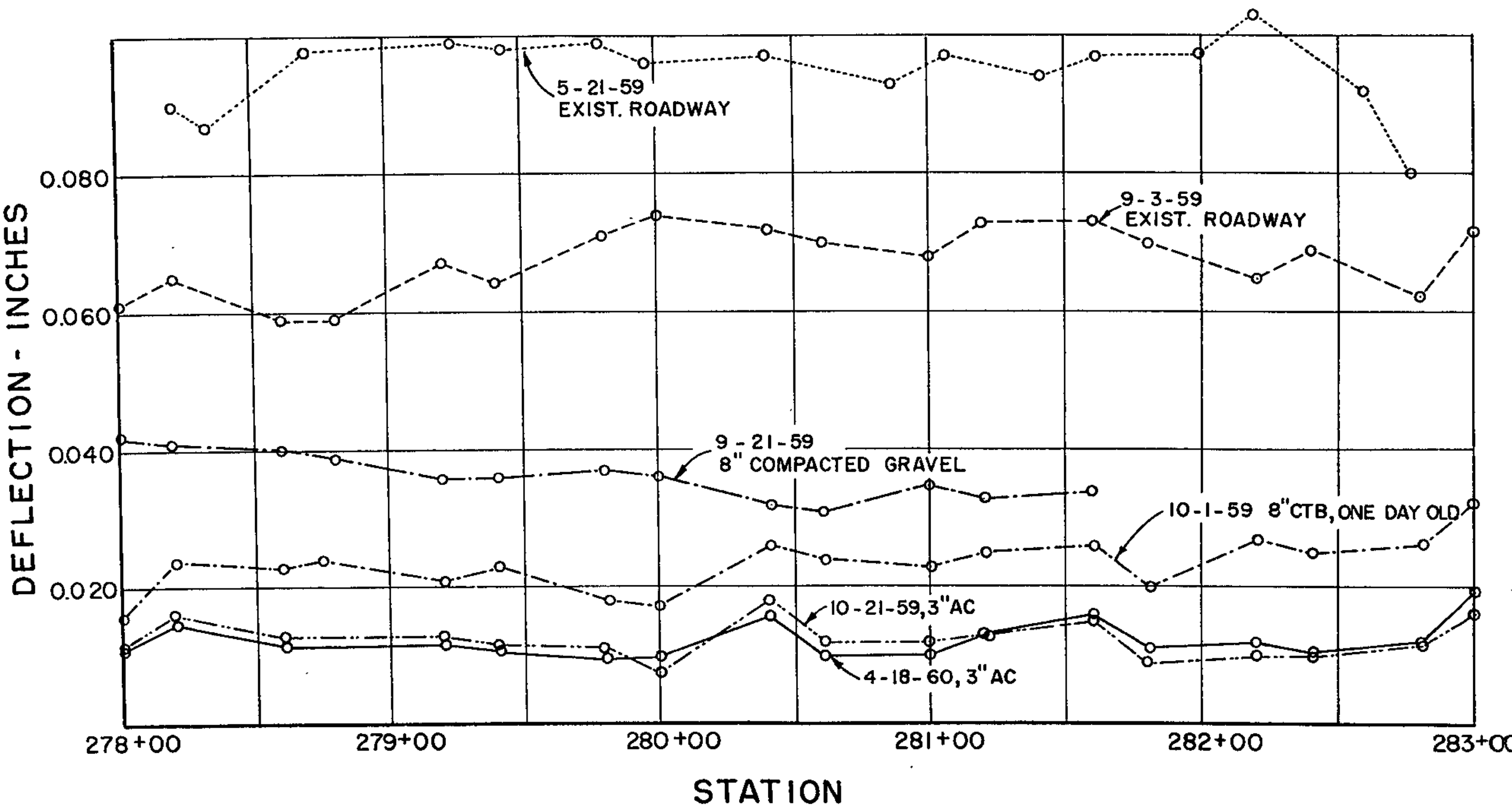

Figure 7

DEFLECTIONS - ROAD III - SAC - 232 - A
SOUTHBOUND LANE - OUTER WHEEL TRACK
SECTION II (a)

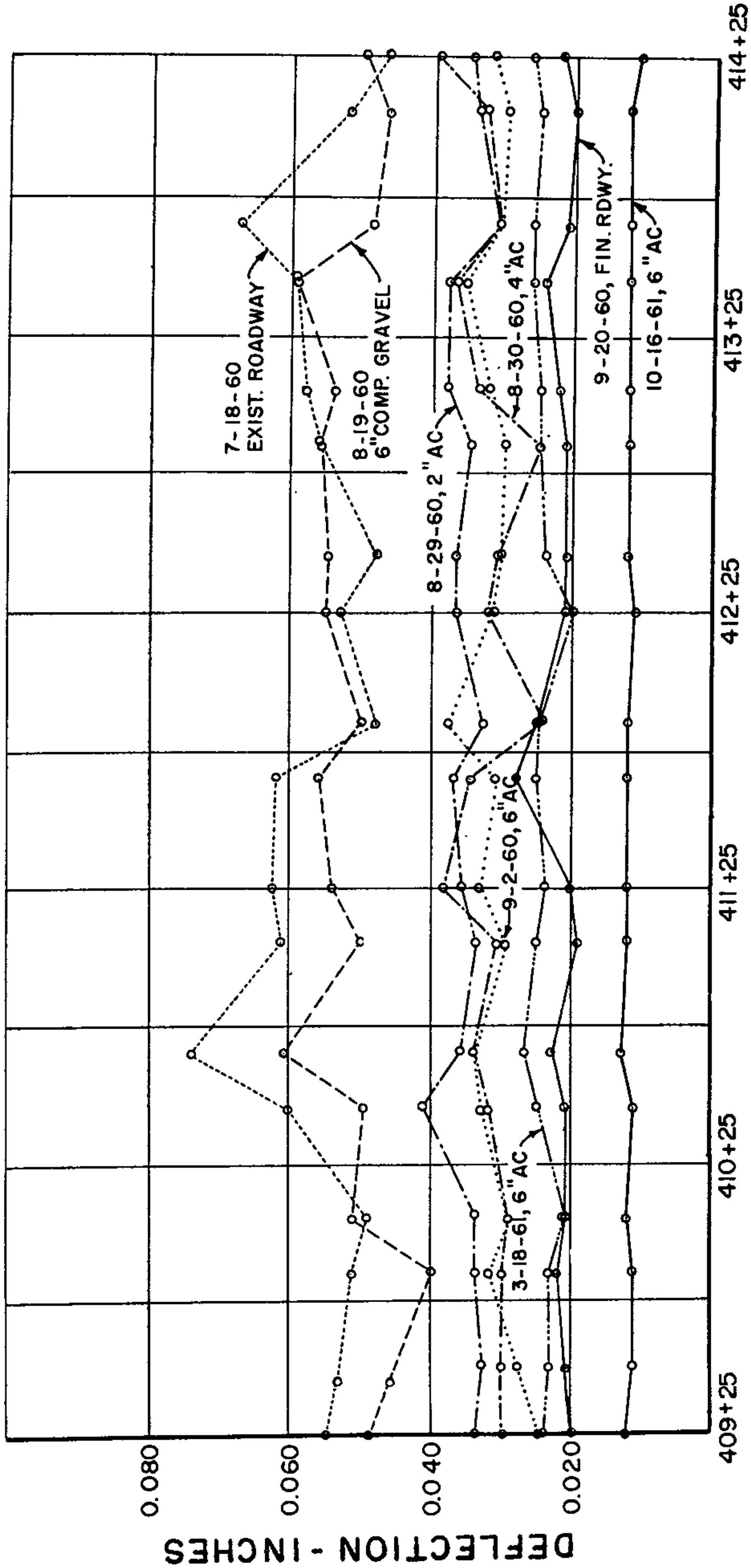

Figure 8

DEFLECTIONS - ROAD III-SAC-232-A
SOUTHBOUND LANE-OUTER WHEEL TRACK
SECTION II (b)

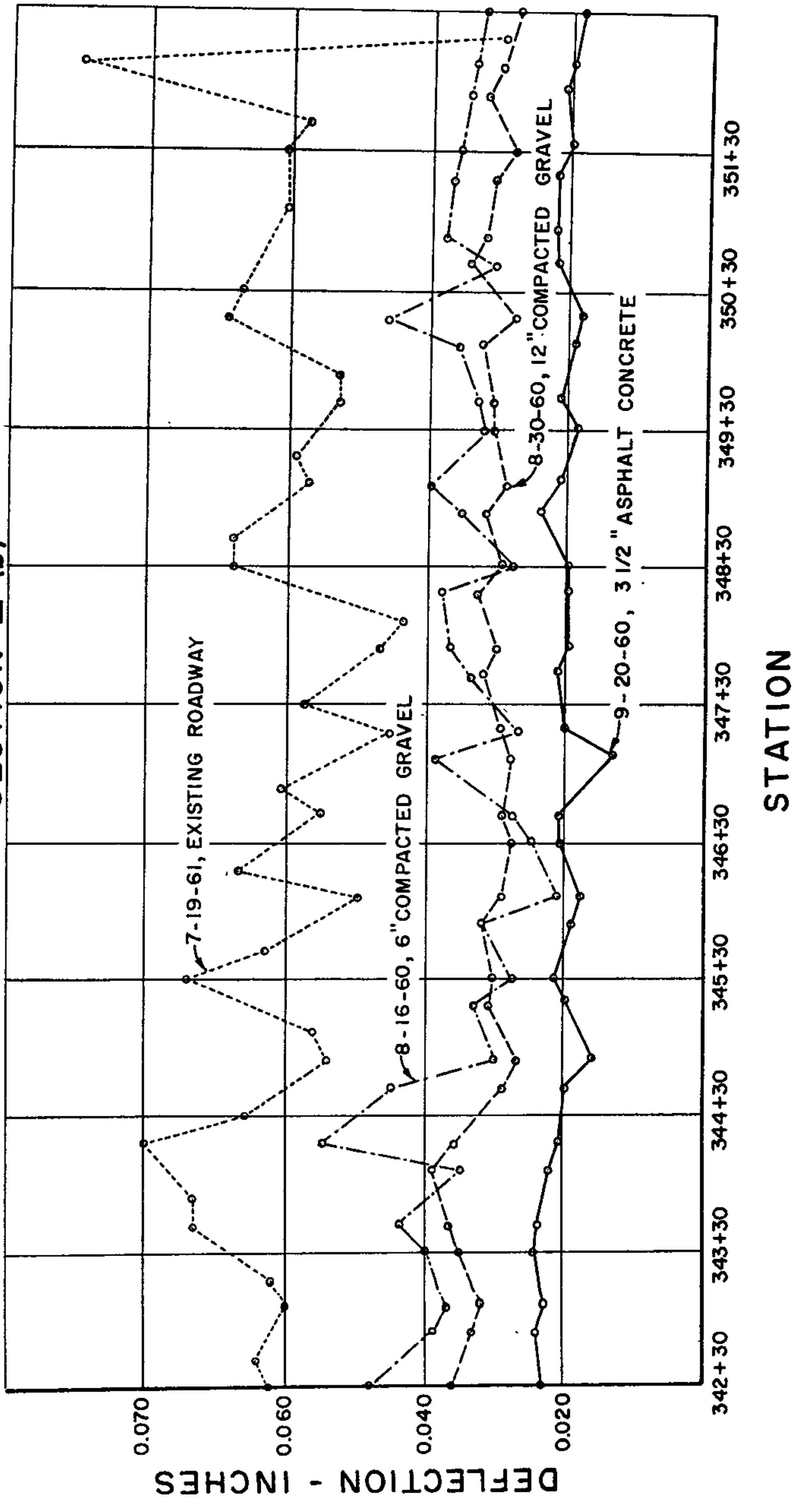

Figure 9

ADDITIONAL PAVEMENT REQUIRED TO STRENGTHEN EXISTING ASPHALT SURFACED PAVEMENTS

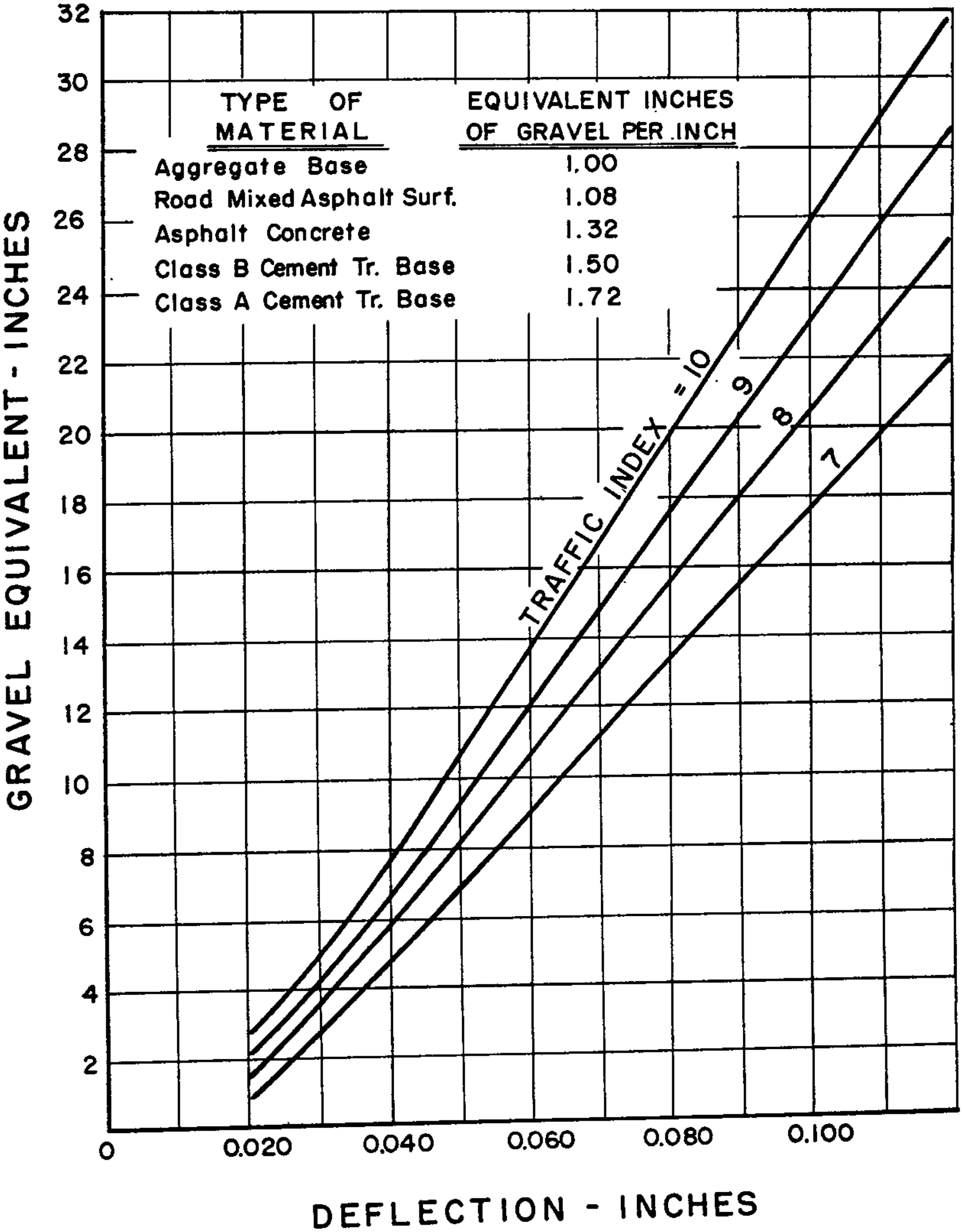

Figure 10